

Naval Surface Warfare Center Carderock Division

West Bethesda, MD 20817-5700

NSWCCD-65-TR-2003/39 September 2003

Survivability, Structures, and Materials Directorate
Technical Report

SIDER Testing of Two Range Safety Craft

by

Colin P. Ratcliffe, *United States Naval Academy*

Roger M. Crane, *Naval Surface Warfare Center*

NSWCCD-65-TR-2003/39 SIDER Testing of Two Range Safety Craft



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To: Chief of Naval Research (ONR 334)

SUBJ: STRUCTURAL IRREGULARITY AND DAMAGE EVALUATION ROUTINE
(SIDER) INSPECTION OF SHIP STRUCTURES

Ref: (a) Composite High-Speed Vehicle Task for FY03, Program Element 0603236N

Encl: (1) NSWCCD-65-TR-2003/39, *SIDER Testing of Two Range Safety Craft*

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2. Comments or questions may be referred to Dr. Roger M. Crane, Code 6553; telephone (301) 227-5126; e-mail, CraneRM@nswccd.navy.mil.

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**Naval Surface Warfare Center
Carderock Division**

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Enclosure (1)

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14. ABSTRACT This report documents work performed by the Naval Surface Warfare Center, Carderock Division in support of The Technical Cooperation Program (TTCP), composite panel TP-7, Operating Assignment 026, on the durability assessment of composites in the service environment. This is part of KTA-10, composite performance and long-term durability under dynamic, thermal and shock loading. This report presents the results of single Structural Irregularity and Damage Evaluation Routine (SIDER) inspections of two range safety craft (RSC) in the United Kingdom. The primary task of these craft is providing range surveillance and clearance in coastal areas. The hull is a rib stiffened GRP design. The SIDER inspection identified several regions that had changes in structural stiffness. One of the indications corresponded to a loose hull penetration. The most significant feature was an area of skin to stiffener debonding. In addition, there were other areas identified which were physically hidden from view. It is recommended that details of the ship construction be reviewed to see if these are areas that have known stiffness variation due to construction.					
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Administrative Information

The work described in this report was performed by the Structures and Composites Department (Code 65) of the Survivability, Structures and Materials Directorate at the Naval Surface Warfare Center, Carderock Division (NSWCCD). The work was funded by the Chief of Naval Research (ONR 334) as part of the Composite High-Speed Vehicle Task for FY03, Program Element 0603236N.

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Background and Introduction

This report presents the results of a single Structural Irregularity and Damage Evaluation Routine (SIDER) inspection of two range safety craft (RSC). The primary task of these craft is providing range surveillance and clearance in coastal areas around the United Kingdom. Twelve craft in total were built from 1978 to 1984. Standard engines were Rolls Royce C8M-410, replaced by 612 kW Volvo Penta TAMDI22D during 1995 giving a top speed of 22 knots and a range of 300 miles at 20 knots. The twin-screw craft have a displacement of 20.2 tons (full load), a length of 48.2 feet (14.7 meters), a beam of 11.5 feet (3.5 meters) and a draught of 4.3 feet (1.3 meters). A photograph of a Range Safety Craft is in Figure 1.

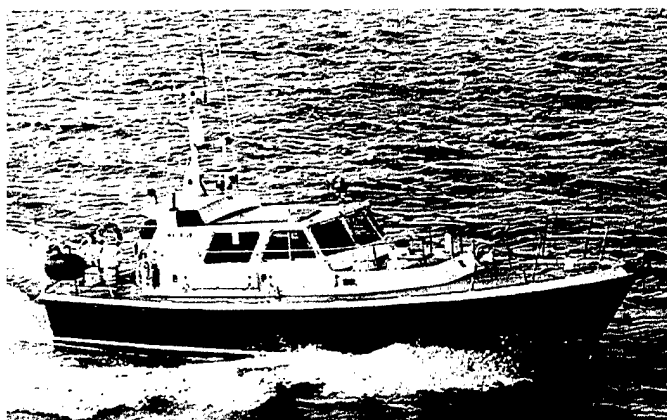


Figure 1. Range Safety Craft

One of the RSCs tested was RSC8126 (formerly named *Sir Cecil Smith*), a GFE vessel operated by Smit Internat. The other vessel we tested was identified as a “police” vessel. The pennant number is unknown, but was probably RSC8125 or RSC8129, since these RSCs are currently operated by the Ministry of Defence Police.

Early in November 2002, The Technical Cooperation Program (TTCP) composite panel TP-7 had their annual meeting at the United States Naval Academy. One of the study assignments presented was Study Assignment 29 on the Durability assessment of composites in the service environment. This is part of the KTA-10: Composite performance and long-term durability under dynamic, thermal and shock loading. The presentation described the Structural Irregularity and Damage Evaluation Routine (SIDER) which is currently being developed at the United States Naval Academy and NSWC, Carderock Division by Drs. Colin Ratcliffe and Roger Crane, respectively.

There was significant interest in this technology and the ability of the SIDER to locate areas of structural differences in complex composite structures. The interest by the member countries was significant enough that the study assignment was elevated to an operating assignment. In this, the member nations work together in the development and transfer of the technology for the mutual benefit of the military of each nation.

In late November 2002, Dr. Paul Curtis, the United Kingdom (UK) National Leader, contacted Dr. Crane and expressed interest by Alan Groves from the MoD at Abbeywood (Bristol) to use SIDER to inspect a GRP hull and sandwich decking on an *Archer*-Class vessel.

There have been issues of bonding of the deck to the hull on some ships in this class. It was requested that Drs. Ratcliffe and Crane contact Alan Daniel to discuss the possibility of going to the UK and inspecting the vessels with SIDER.

After several conference calls between the U.S. representatives and representatives of the MoD, it was decided that the SIDER technique may have the capability of locating damage in the *Archer*-Class decks, as well as other composite ship components. While Drs. Ratcliffe and Crane were in the United Kingdom testing an *Archer*-Class vessel, the opportunity was taken to visit VT Halmatic Ltd., and test parts of two range safety craft. A section along the starboard side was selected because of its accessibility on both craft during the testing period. Figure 2 shows a general view of the RSC during testing in the facilities at VT Halmatic Limited, Portsmouth, United Kingdom, approximately located at 50° 50.72' N 001° 06.95' W. Testing took place on July 16-17, 2003.

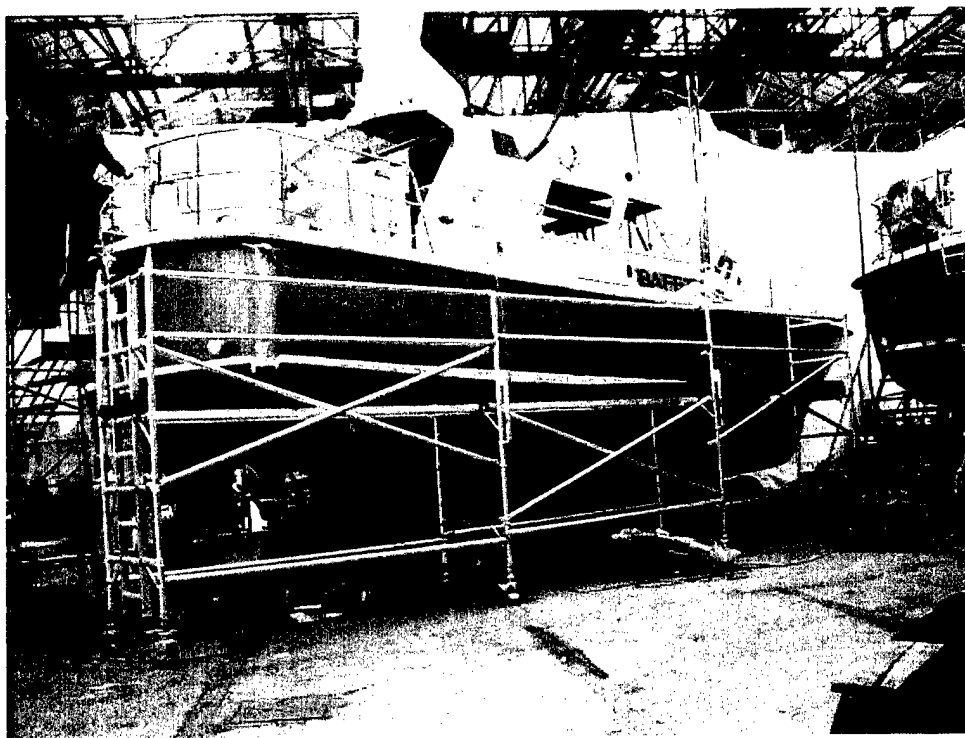


Figure 2. General View of RSC-8126 during SIDER Testing

The SIDER procedure looks at either the entire structure, or large parts of a structure, and identifies locations where there is variability in structural stiffness. These areas either are due to the design stiffness variability of the structure itself, or are manufacturing defects or in-service damage. After a preliminary SIDER, a follow-up SIDER can be used to show the change which has taken place over time. This change is attributable to damage occurring between the two examinations. For this particular project, each hull section was subject to a single SIDER. Since each hull section was nearing completion of its overhaul, any identified features would be coincident with area that had in-service damage.

Grid

In order to conduct a SIDER analysis, the structure needs to be marked with a mesh of test points. For the best results, the mesh should be uniform. However, some irregularity is acceptable. For the sides of the RSCs, it was decided to use a basic mesh size of nine inches in the horizontal direction, and 4 inches in the vertical direction. The global origin for measurements was the intersection of the wood rub strip with a vertical metal corner plate running down the aft starboard quarter, as shown in Figure 3. The X-direction was forward along the strip. Hence, the slight curvature in the strip meant the axis was also curved. The Y-direction was plum bob vertically upwards (that is, not exactly orthogonal to the strip) and was the distance from the center of the wood strip. The Z-direction was normally outward from the hull surface. Using this style of coordinates and axes means that SIDER features can be more easily located on the structure.

The mesh was centered on the wooden rubbing strip that was on the RSC police vessel. It was not possible to put ± 2 -inch grid points above or below this strip because there was insufficient space to get the hammer in to the correct location. Therefore, the first two rows of grid points were set at ± 2.5 inches in the vertical direction.

RSC8126 did not have the wooden rubbing strip. Therefore, the missing location was marked with masking tape, and the same grid was established using this tape as reference.

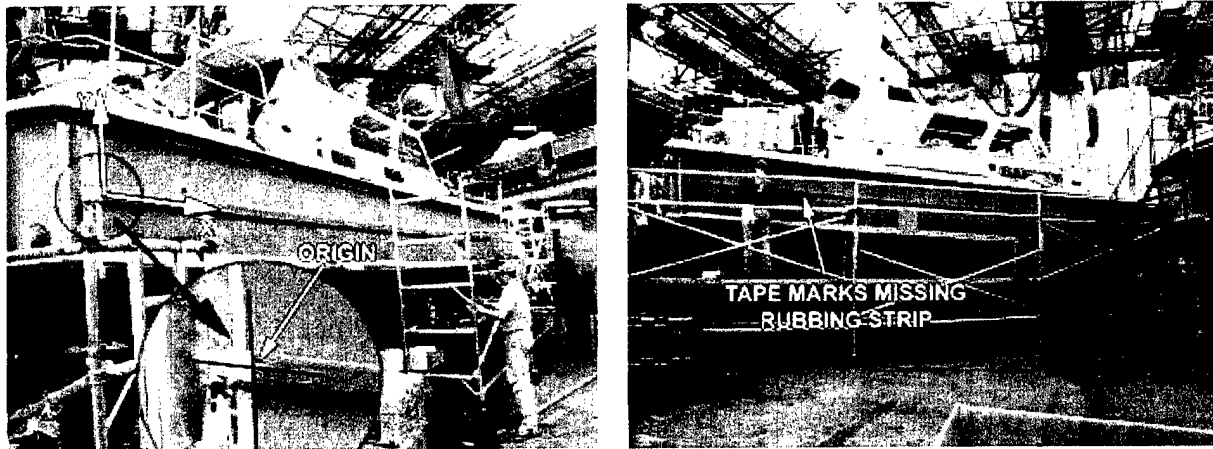


Figure 3. Global Origin and Axes

Figure 4 shows the test grid with grid point numbering and the grid overlayed on a photograph of RSC Police.

11	21	31	41	51	61	71	81	91	101	111	121	131	141	151	161	171	181	191	201	211	221	231	241	251	261	271	281	291	301	311	321	331	341	351
12	22	32	42	52	62	72	82	92	102	112	122	132	142	152	162	172	182	192	202	212	222	232	242	252	262	272	282	292	302	312	322	332	342	352
13	23	33	43	53	63	73	83	93	103	113	123	133	143	153	163	173	183	193	203	213	223	233	243	253	263	273	283	293	303	313	323	333	343	353
14	24	34	44	54	64	74	84	94	104	114	124	134	144	154	164	174	184	194	204	214	224	234	244	254	264	274	284	294	304	314	324	334	344	354
15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175	185	195	205	215	225	235	245	255	265	275	285	295	305	315	325	335	345	355
16	26	36	46	56	66	76	86	96	106	116	126	136	146	156	166	176	186	196	206	216	226	236	246	256	266	276	286	296	306	316	326	336	346	356
17	27	37	47	57	67	77	87	97	107	117	127	137	147	157	167	177	187	197	207	217	227	237	247	257	267	277	287	297	307	317	327	337	347	357
18	28	38	48	58	68	78	88	98	108	118	128	138	148	158	168	178	188	198	208	218	228	238	248	258	268	278	288	298	308	318	328	338	348	358

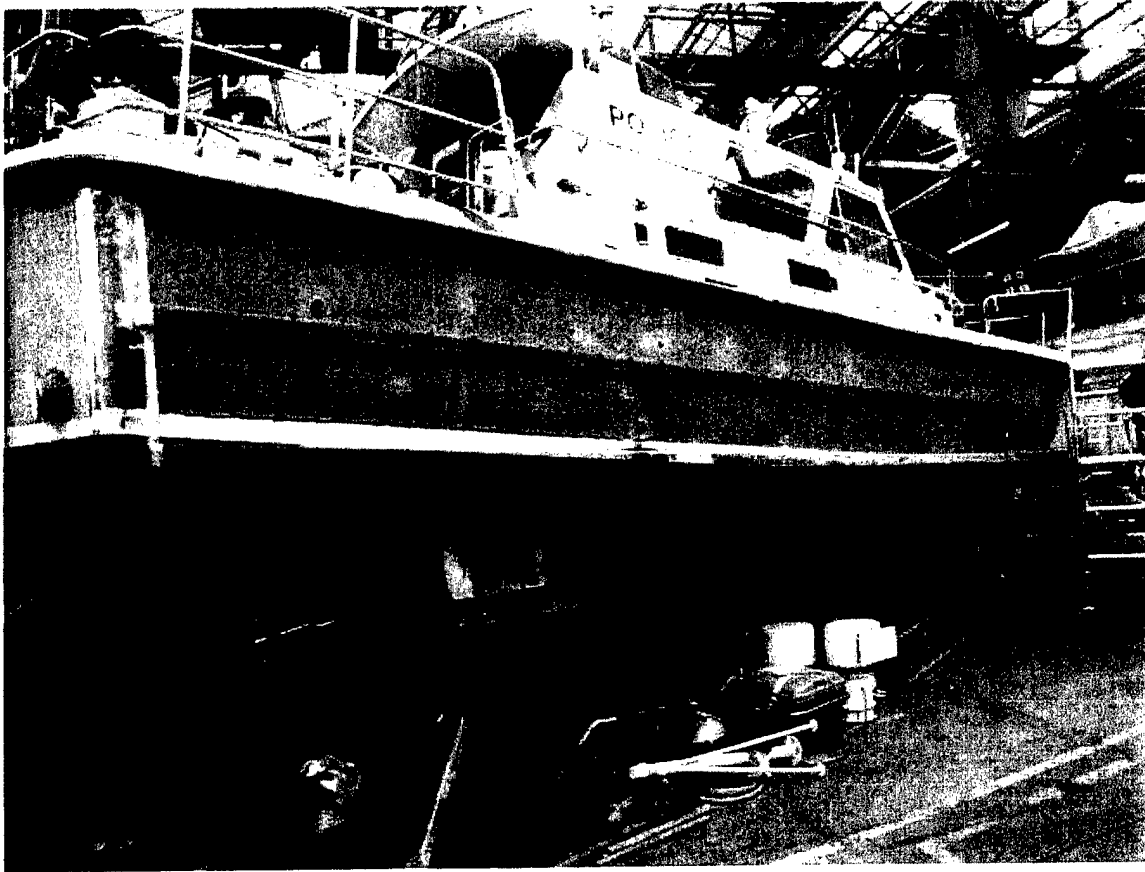


Figure 4. Test Grid for RSC

Accelerometer Locations

Most SIDER tests use four accelerometers, arranged on a close-to symmetric pattern. The symmetry is deliberately broken so that the accelerometer locations are partly randomized. Additional transducers may be required if the structure is not particularly resonant. In this case, each transducer might not “see” the impact at all locations. It is generally best if at least four transducers “see” the impact at any point on the structure. For this study, even though the structure was not very resonant, it was decided to use four accelerometers. This was based on provisional testing, where a pulse at one end of the structure was readily observable at the other end. As described later, the SIDER used the data from all accelerometers. All accelerometers had a nominal sensitivity of 100 mV/g.

The locations of the accelerometers are shown in Table 1. The absolute location of the transducers is estimated to have an accuracy of $\pm 1.5''$.

Accelerometers mounting bases were bonded with cyanoacrylate superglue to the outer surface. The accelerometers were then mounted by stud to the mounting bases.

Table 1. Location of the Accelerometers

Accelerometer	Analyzer Channel	X	Y	Z
A	2	3'9"	-0'8"	0"
B	3	9'9"	1'1"	0"
C	4	19'6"	0'6"	0"
D	5	24'9"	-1'1"	0"

Data Acquisition and Quality

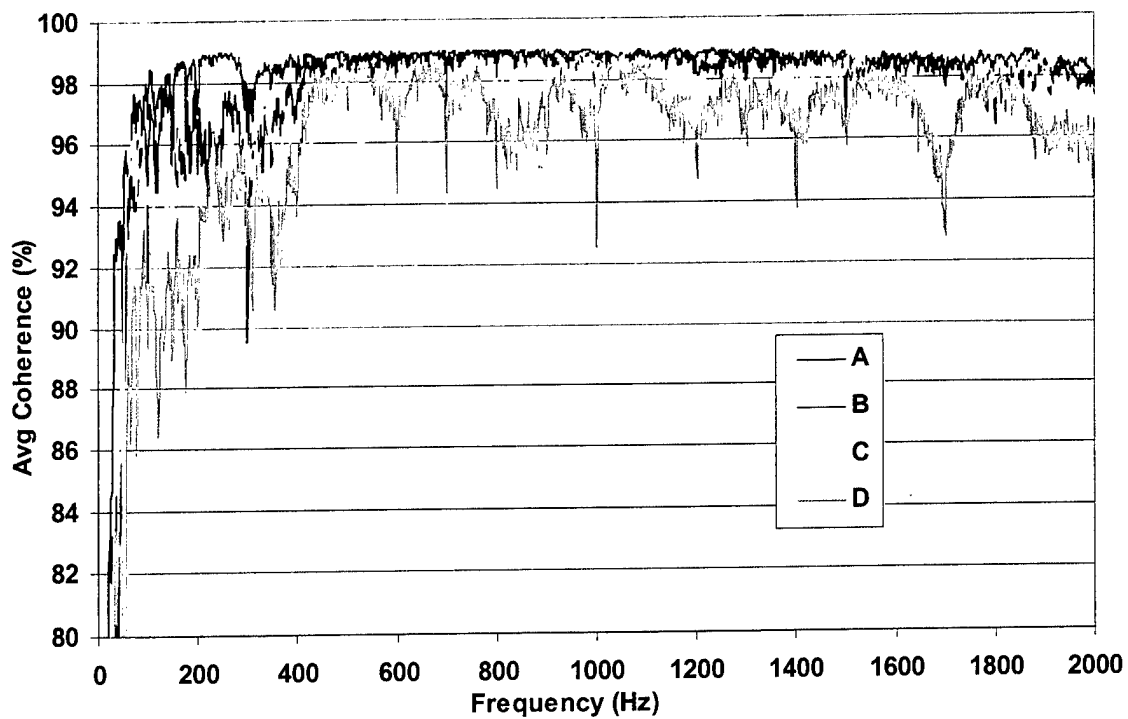
There were a total of three different tests conducted on the two range safety craft. There were two tests on RSC Police, one using the small sized modally tuned hammer and one using the midsize modally tuned sledgehammer. There was one test on RSC8126, using the midsize sledge. Data acquisition details are shown in Table 2.

Table 2. RSC8126 Data Acquisition Details

Detail	RSC Police	RSC Police	RSC8126
Test ID	R1	R2	R3
Hammer	Small	Midsize sledge	Midsize sledge
Tip	Nylon	Grey	Grey
Frequency range	0-2 kHz	0-1 kHz	0-1 kHz
Resolution	1.25 Hz	0.625 Hz	0.625 Hz
Response exponential window constant	0.3 s	0.3 s	0.3 s

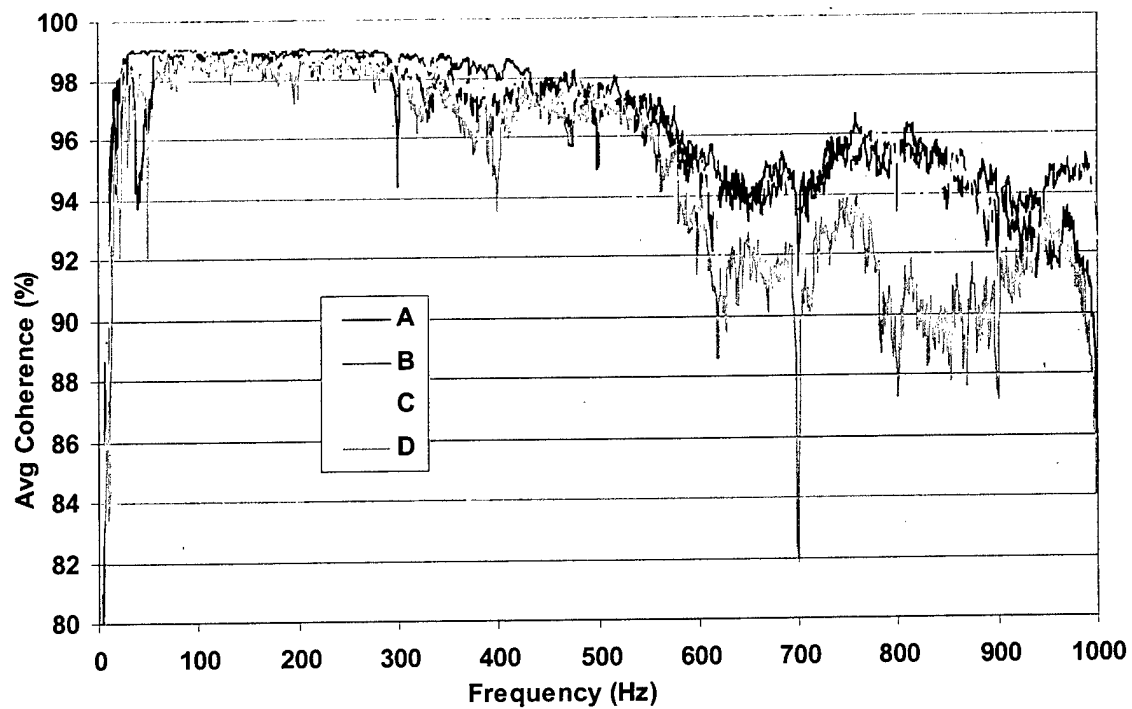
Data for each impact point were spectrally averaged for two hits. On site, the data quality was primarily assessed by observation of the individual coherence functions. When the coherence was atypically poor, the measurement was repeated until either the coherence improved, or it was assessed that the low coherence was a structural issue rather than a test issue.

After the fact, the data quality is assessed by the average coherence. Figure 5 and Figure 6 show the average coherence for each test. In keeping with our standard procedures, the average coherence is shown separately for each accelerometer. Note that the coherence axis for each graph is expanded, and only shows the range 80-100%. We would normally consider a high quality data set to have an average coherence in excess of 95%, and preferably more than 98%. As discussed below, we have very high quality data in frequency ranges where there was sufficient input energy.



(RSC Police with small hammer)

Figure 5. Average Coherence for Test ID R1



(RSC8126 with midsize sledge)

Figure 6. Average Coherence for Test ID R3

This was the first time that the small modally tuned hammer was used to excite a structure as large as this. Normally, this hammer has only been used for small structures in a laboratory situation. A decision was made to try to use it because of the nonresonant nature of the RSCs. A small initial test showed that the data obtained using the small hammer had good coherence up to 2 kHz. However, as shown in Figure 5, the low frequency data (below about 500 Hz) had a poor coherence. These features are not surprising. The low frequencies correlate to overall structural vibration, and the small hammer did not impart enough energy to excite this type of motion. The high frequencies are more related to short wavelength motion that can propagate along surface layers without exciting the overall structural motion.

This project, therefore, gave a unique opportunity to compare the performance of SIDER on a large structure when different excitation methods are used. This report presents the overall results and major conclusions. Detailed analysis of the effort of structural motion for the SIDER testing is left to a later date.

SIDER Test Results

Based on the coherence data, the SIDER analysis was conducted from 500 to 2 kHz for test ID R1, and from 50 to 450 Hz for Test IDs R2 and R3, these being the frequency ranges where the average coherence is above about 98%.

Accelerometer Effect

It is a documented aspect of the SIDER algorithm that the procedure may produce features at the locations of the accelerometers. This is a theoretical aspect, but the effect has only been observed once before, while testing a 100% rubber submarine component. The component did not comply with one structural requirement for SIDER – that the structure be resonant. Figure 7 a) shows the SIDER results for Test ID R2 with the approximate positions of the accelerometers marked with black dots. There is some concern that at least three of the features are coincident with the accelerometers. Figure 7 b) through Figure 7 e) enhance this concern by showing the SIDER results obtained by using just one accelerometer at a time. It should be noted that this single accelerometer analysis is *not* part of the documented SIDER procedure, and is used here for demonstrative and analytical purposes only.

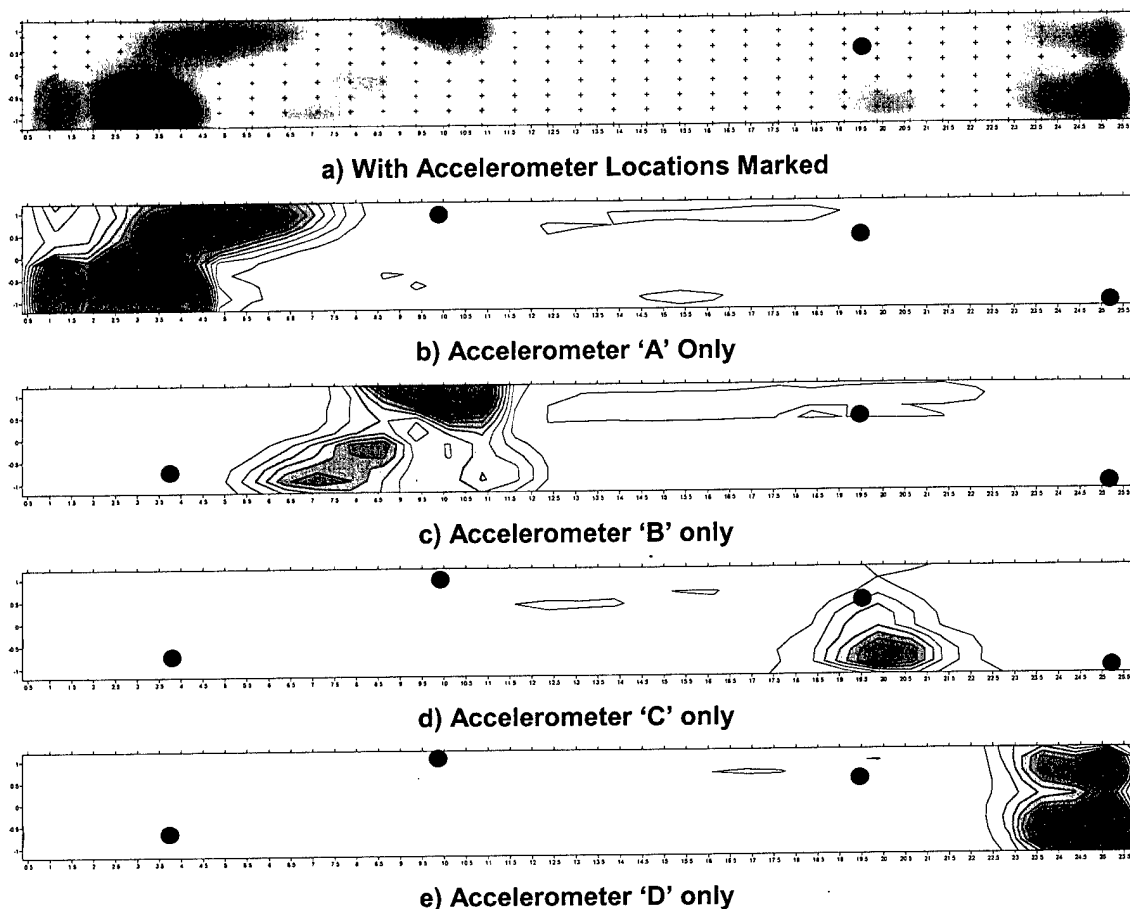


Figure 7. Test ID R2 SIDER Results

The SIDER theory suggests that these 'accelerometer features' are only effective for about two grid points from the accelerometer location, and beyond that the results are unaffected. Therefore, it was decided to implement a blanking algorithm to see if the small hammer would provide results similar to those from the larger sledgehammer. The blanking algorithm uses data from all four accelerometers for most of the structure. However, when the analysis is near an accelerometer, the results from the nearby accelerometer are 'blanked' and the results only obtained from the other three remote accelerometers. Figure 8 shows the effect of using the algorithm for this structure. By comparing Figure 7 a) with Figure 8, it is readily seen that this accelerometer problem is solved.

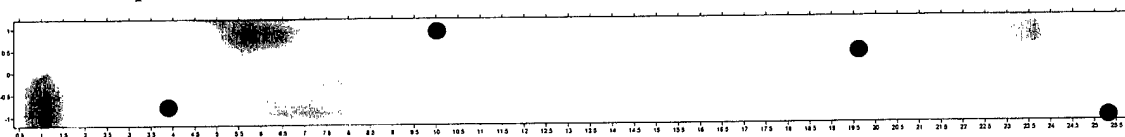


Figure 8. Test ID R2 SIDER results with blanking algorithm employed

Previously, thought had been put into whether this blanking routine should be employed as a standard feature of SIDER. Based on previous experience where the accelerometer problem was not of concern, it was decided that SIDER did not need the additional computational aspects of the blanking routine. It now seems it may be appropriate to incorporate the blanking routine

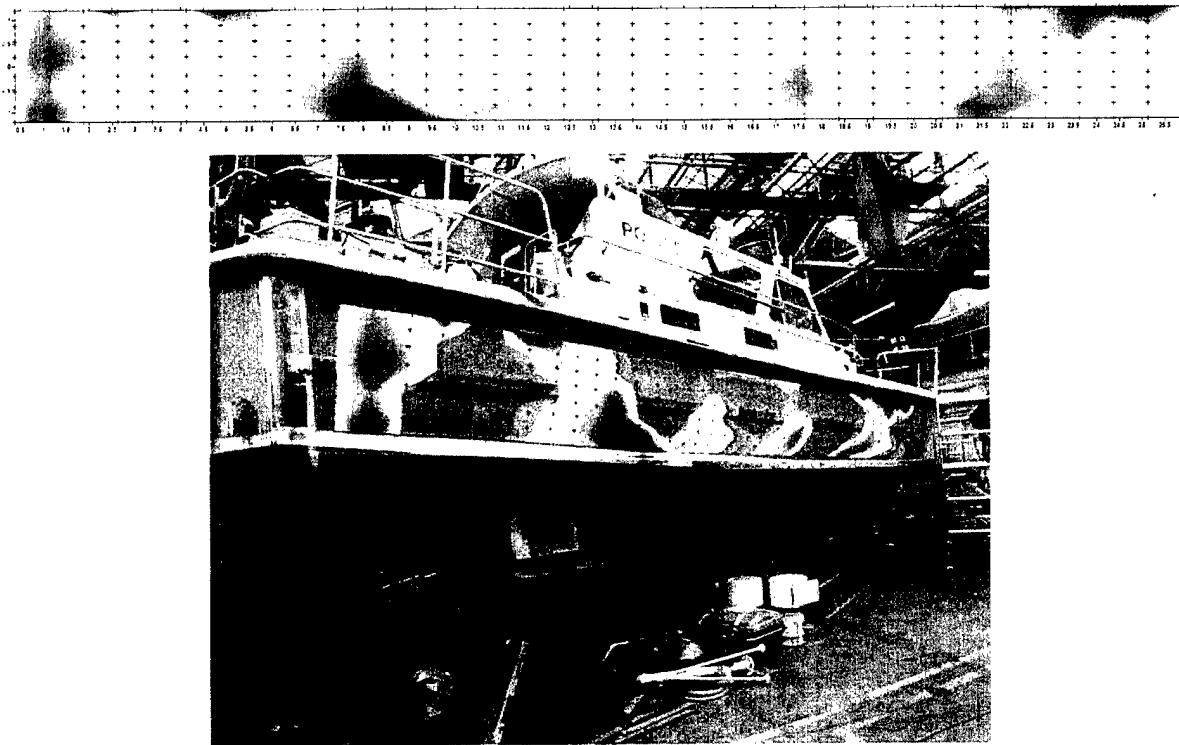
as a standard aspect of the algorithm. All SIDER results shown later in this report include the blanking algorithm analysis.

SIDER results for Test IDs R1, R2 and R3

Figure 9 through Figure 11 show the SIDER results for the RSC Police tests using the small and midsize hammers (Test IDs R1 and R2 respectively), and the test of RSC 8126 (Test ID R3). All plots are to the same scale – the same shade of red has the same SIDER value in all graphs and photographs.

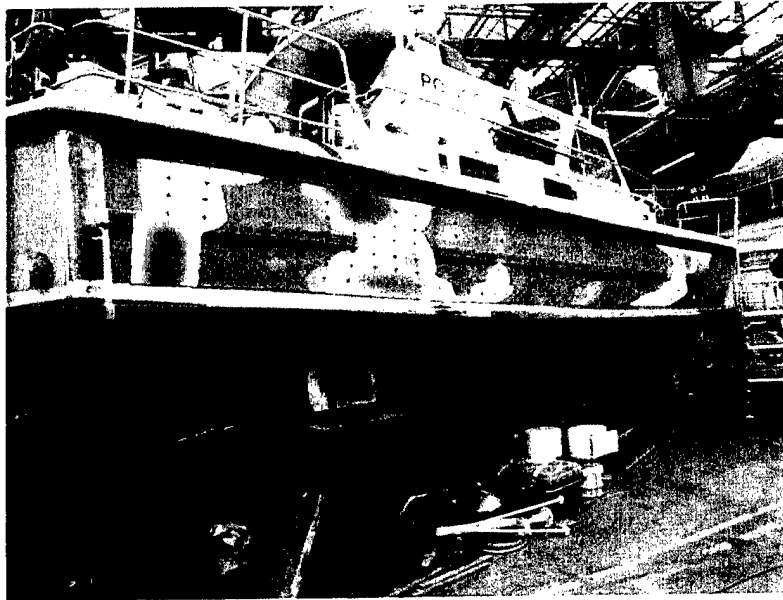
On these plots the small crosses show the test grid and the axes legends show the distance in feet from the global origin. While SIDER is a directional test, the results shown here are solely for the fore-aft analyses. The analysis requires a reasonably large number of test points in the direction of the analysis. For these tests it was decided to limit the interest to the fore-aft analysis, and therefore the test grid was restricted in number of points in the vertical (Y) direction. This saved a significant amount of test time. This limitation was imposed because the test section had a high aspect ratio.

The SIDER results are shown as contour plots, and separately overlaid on photographs of the RSCs. Note that the contour plots can be used to accurately locate features on the structure. In this report, because of the foreshortening of the photographs, the features can actually be several inches from their actual position on the photographs. As mentioned previously, all results include the blanking algorithm.



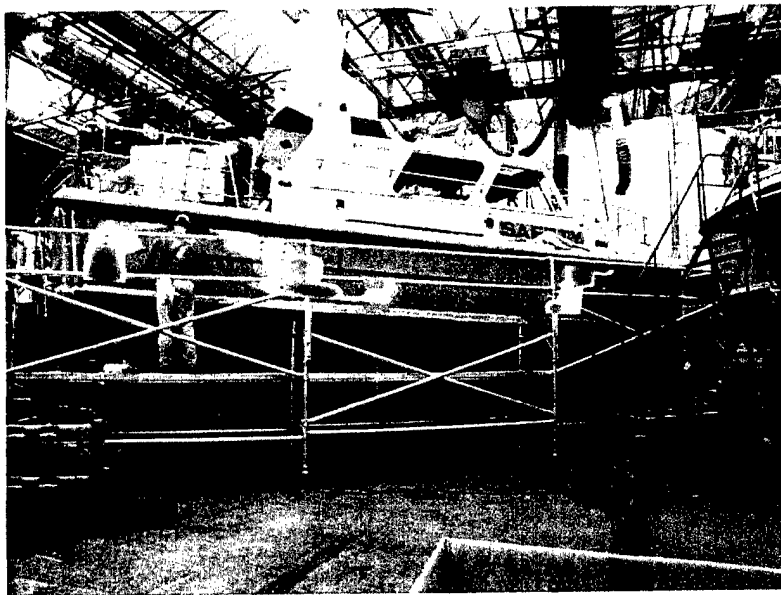
(RSC Police with small hammer)

Figure 9. SIDER Results for Test ID R1



(RSC Police with midsize sledge)

Figure 10. SIDER Results for Test ID R2



(RSC8126 with midsize sledge)

Figure 11. SIDER Results for Test ID R3

Discussion of SIDER Results

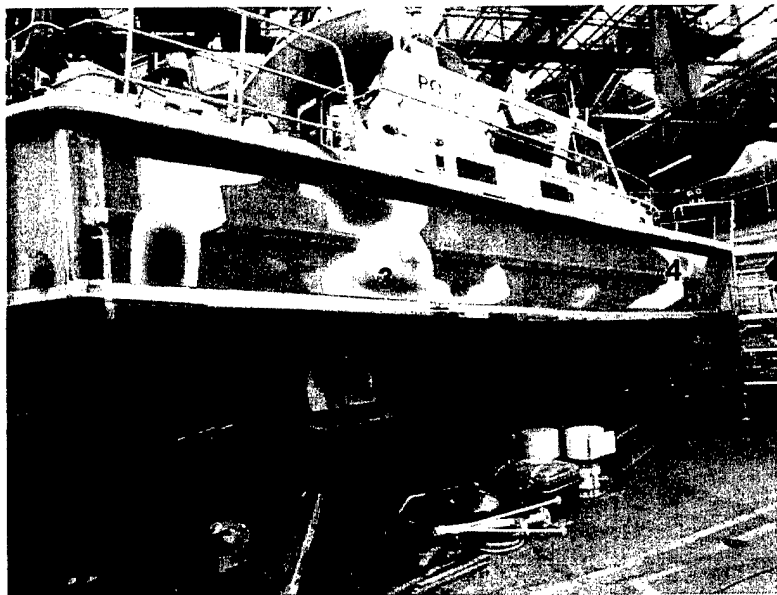
Comparison of Small and Midsize Hammers

The two results show a remarkable agreement in both pattern of features and magnitude of SIDER values. Both tests identify the same basic regions as “clear” of irregularity. The main difference seems to be that the features identified by the small hammer are slightly larger in both magnitude and area.

Comparison of RSC Police and RSC8126 Using Midsize Sledge Hammer

The two RSCs are sister vessels. There are, though, some differences. RSC Police had its starboard engine installed, whereas RSC 8126 had no engines in place. Also, there were some differences in internal attachments to the hull, and the hull penetration layouts were different. Despite these differences, the SIDER inspections have produced very similar plots of structural irregularity features. This result suggest that a baseline SIDER from one vessel may be useful in identifying problems with another hull.

Figure 12 is similar to Figure 10, but with several features marked (the mesh has been removed from the original figure to aid clarity).



(RSC Police with midsize sledge)

Figure 12. SIDER Results for Test ID R2 with Marked Features

Feature 1 is coincident with an internal bulkhead. Examination of this part of the RSC Police hull by Keith Vernon, Senior Surveyor, Lloyd's Registry of London, confirmed that this SIDER feature had identified damage (probably delamination or debonding) between the main hull shell and the bulkhead. This is a high-risk part of the vessel, since it often gets hit during alongside maneuvers. There was also some nearby cracking of the internal bulkhead, but this

was not in the area that had been SIDER inspected. Mr. Vernon did note, though, that the identification of this crack was significantly aided by knowledge of the damage location identified by the SIDER analysis.

Feature 2 is strong on RSC Police, but minimal on RSC 8126. Internally to RSC Police, there is a wiring support harness at this location. It does not exist in the RSC 8126. It is speculated that SIDER has located the wiring harness, but it is possible that there is other hidden structural irregularity. The wiring harness is shown in Figure 13.

Feature 3 shows on the results for both craft. There were no obvious problems or structural features at this location, but since the feature is apparent on both RSC results, it presumably maps to some structural or damage-related stiffness variation. The thick noise and vibration lagging on the inside surface of the hull precluded a detailed investigation of this area.

Feature 4 also shows on the results for both craft. At this point inside the hull there is a small galley, and it was not possible to get to the inside surface of the hull shell. However, this is another high-risk part of the hull, prone to impact damage during alongside evolutions.



Figure 13. Wiring Harness inside RSC Police

Conclusions and Recommendations

The SIDER technique was used to inspect the starboard side hull of two RCSs from the main deck to the water line. The hull is a rib stiffened GRP design. The SIDER inspection identified several regions that had changes in structural stiffness. One of the indications corresponded to a loose hull penetration. The most significant feature, identified previously as region 1, was an area of skin to stiffener debonding. In addition, there were other areas identified which were physically hidden from view, given as regions 3 and 4. It is recommended that details of the ship construction be reviewed to see if these are areas that have known stiffness variation due to construction. If they are not, then these are suspect areas and more detailed non-destructive evaluation methods, such as ultrasonic inspection should be used to verify structural integrity. In general, it certainly can be stated that the SIDER technique can readily locate areas on composite structures where stiffness variations occur which are attributable either to structural design or structural anomalies.